SOLAR/1018-79/14

Solar Energy System Performance Evaluation

STEWART-TEELE-MITCHELL
SINGLE-FAMILY RESIDENCE
Malta, New York
November 1978 Through March 1979

U.S. Department of Energy

National Solar Heating and
Cooling Demonstration Program

National Solar Data Program

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SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

STEWART-TEELE-MITCHELL
MALTA, NEW YORK

NOVEMBER 1978 THROUGH MARCH 1979

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NATIONAL SOLAR DATA PROGRAM REPORTS

Reports prepared for the National Solar Data Program are numbered under specific format. For example, this report for the Stewart-Teele-Mitchell project site is designated as SOLAR/1018-79/14. The elements of this designation are explained in the following illustration.

SOLAR/1018-79/14

Prepared for the National Solar Data Program

Report Type Designation

Demonstration Site

Year

- Demonstration Site Number:

  Each project site has its own discrete number - 1000 through 1999 for residential sites and 2000 through 2999 for commercial sites.

- Report Type Designation:

  This number identifies the type of report, e.g.,

  - Monthly Performance Reports are designated by the numbers 01 (for January) through 12 (for December).

  - Solar Energy System Performance Evaluations are designated by the number 14.

- Solar Project Descriptions are designated by the number 50.

- Solar Project Cost Reports are designated by the number 60.

These reports are disseminated through the U. S. Department of Energy Technical Information Center, P. O. Box 62, Oak Ridge, Tennessee 37830.

1. FOREWORD

The National Program for Solar Heating and Cooling is being conducted by the Department of Energy under the Solar Heating and Cooling Demonstration Act of 1974. The overall goal of this activity is to accelerate the establishment of a viable solar energy industry and to stimulate its growth to achieve a substantial reduction in nonrenewable energy resource consumption through widespread applications of solar heating and cooling technology.

Information gathered through the Demonstration Program is disseminated in a series of site-specific reports. These reports are issued as appropriate and may include such topics as:

- o Solar Project Description
- o Design/Construction Report
- o Project Costs
- o Maintenance and Reliability
- o Operational Experience
- o Monthly Performance
- o System Performance Evaluation

The International Business Machines (IBM) Corporation is contributing to the overall goal of the Demonstration Act by monitoring, analyzing, and reporting the thermal performance of solar energy systems through analysis of measurements obtained by the National Solar Data Program.

The Solar Energy System Performance Evaluation Report is a product of the National Solar Data Program. Reports are issued periodically to document the results of analysis of specific solar energy system operational performance. This report includes system description, operational characteristics and capabilities, and an evaluation of actual versus expected performance. The Monthly Performance Report, which is the basis for the Solar Energy System Performance Evaluation Report, is published on a regular basis. Each parameter presented in these reports as characteristic of system performance represents over 8,000 discrete measurements obtained each month by the National

Solar Data Network (NSDN). Documents referenced in this report are listed in Section 6, "References." Numbers shown in brackets refer to reference numbers in Section 6.

This Solar Energy System Performance Evaluation Report presents the results of a thermal performance analysis of the Stewart-Teele-Mitchell solar energy system. The analysis covers operation of the system from November 1978 through March 1979. The Stewart-Teele-Mitchell solar energy system provides DHW preheating and space heating to a single-family dwelling located in Malta, New York. Section 2 presents a summary of the overall system results. A system description is contained in Section 3. Analysis of the system thermal performance was accomplished using a system energy balance technique described in Section 4. Section 5 presents a detailed assessment of the individual subsystems applicable to the site.

The measurement data for the reporting period were collected by the NSDN [1]. System performance data are provided through the NSDN via an IBM-developed Central Data Processing System (CDPS) [2]. The CDPS supports the collection and analysis of solar data acquired from instrumented systems located throughout the country. This data is processed daily and summarized into monthly performance reports. These monthly reports form a common basis for system evaluation and are the source of the performance data used in this report.

2. SUMMARY AND CONCLUSIONS

This section provides a summary of the performance of the solar energy system installed at Stewart-Teele-Mitchell, located in Malta, New York for the period November 1978 through March 1979. This solar energy system is designed to support the DHW preheating and space heating loads. A detailed description of the Stewart-Teele-Mitchell solar energy system operation is presented in Section 3.

2.1 Performance Summary

The solar energy site was unoccupied from November through December 1978. The house was sold in late December and occupied in January 1979. With the exception of the DHW subsystem, the solar energy system operated continuously during this reporting period. The DHW subsystem was activated in early January 1979.

The total incident solar energy was 60.35 million Btu during the reporting period, of which 11.98 million Btu were collected by the solar energy system. Solar energy applied to the DHW and space heating loads was 5.38 million Btu. Solar systems losses were 6.51 million Btu. The cost of operating the solar energy system was 0.99 million Btu.

Solar energy satisfied 13 percent of the DHW requirements and 9 percent of the space heating requirements for an overall solar fraction of 11 percent. The solar energy system provided a fossil fuel savings of 7.25 million Btu and incurred an electrical energy expense of 0.71 million Btu.

The following incidents or conditions affected the solar energy system performance during the reporting period:

The DHW loop pump (EP300) was not activated prior to January 1979. This contributed to a low overall DHW solar fraction.

Mode-determining valve V2 (D400) did not seat properly. When the system was collecting energy, the heat transfer fluid divided at valve V2 and flowed to

both the solar coil in the space heating air loop and to the storage tank. The faulty valve was replaced in March 1979.

The collector loop heat-transfer fluid (glycol/water) was frozen from February 9 through February 15.

2.2 Conclusions

The actual performance of the solar energy system was considerably below the expected performance as measured by the expected solar fraction. The overall solar fraction of 12 percent is approximately one third of the expected value. A colder-than-expected winter was a contributing factor. However, this was partially offset by an average daily total insolation in excess of the long-term value.

Two conditions can be identified that adversely impacted the DHW solar fraction. The first condition was of a temporary nature: no solar energy was applied to DHW preheating during 40 percent of the reporting period because pump P4 (EP300) was turned off. The second condition is a matter of system design: the separate DHW preheat tank is incompatible with the small amount of water being used. Even when the preheat tank water temperature exceeds the thermostatically-controlled auxiliary DHW tank water temperature, electrical energy is used to maintain the temperature of the water in the coventional DHW tank at the thermostat setting. The electrically-heated water in the conventional DHW tank often serves to temper the solar-heated water as it is drawn from the preheat tank.

3. SYSTEM DESCRIPTION

The Stewart-Teele-Mitchell site is a single-family residence in Malta, New York. The home has approximately 1900 square feet of conditioned space. Solar energy is used for space heating the home and preheating domestic hot water (DHW). The solar energy system has an array of flat-plate collectors with a gross area of 432 square feet. The array faces south at an angle of 45 degrees to the horizontal. A glycol/water solution is the transfer medium that delivers solar energy from the collector array to a heat exchanger. Water is then used as the transfer medium that delivers solar energy from the heat exchanger to storage, and to the space heating and DHW loads. Solar energy is stored in the basement in a 1000-gallon insulated tank. Preheated city water is stored in a 75-gallon preheat tank and supplied, on demand, to a conventional 40-gallon DHW tank. When solar energy is insufficient to satisfy the space heating load, an oil-fired furnace provides auxiliary energy for space heating. Similarly, an electrical heating element in the DHW tank provides auxiliary energy for water heating. The system, shown schematically in Figure 3-1, has five modes of solar operation.

Mode 1 - Collector-to-Storage: This mode activates when the collector temperature exceeds the storage temperature by 20°F and terminates when a temperature difference of 3°F is reached. Solar energy is transferred through the heat exchanger that transmits energy from the solar collection loop to the storage loop. Collector loop pump P1 and storage loop pump P2 are operating.

Mode 2 - Collector-to-Space Heating: This mode activates when mode 1 conditions are satisfied and there is a demand for space heating. The collected solar energy bypasses storage and flows directly to the solar heating coil in the air-handling system. Mode diversion valve V2 is open.

Mode 3 - Storage-to-Space Heating: This mode activates when there is a demand for space heating, the temperature at the top of the storage tank exceeds 100°F, and solar energy from the collector is not available. Pump P3 is operating.

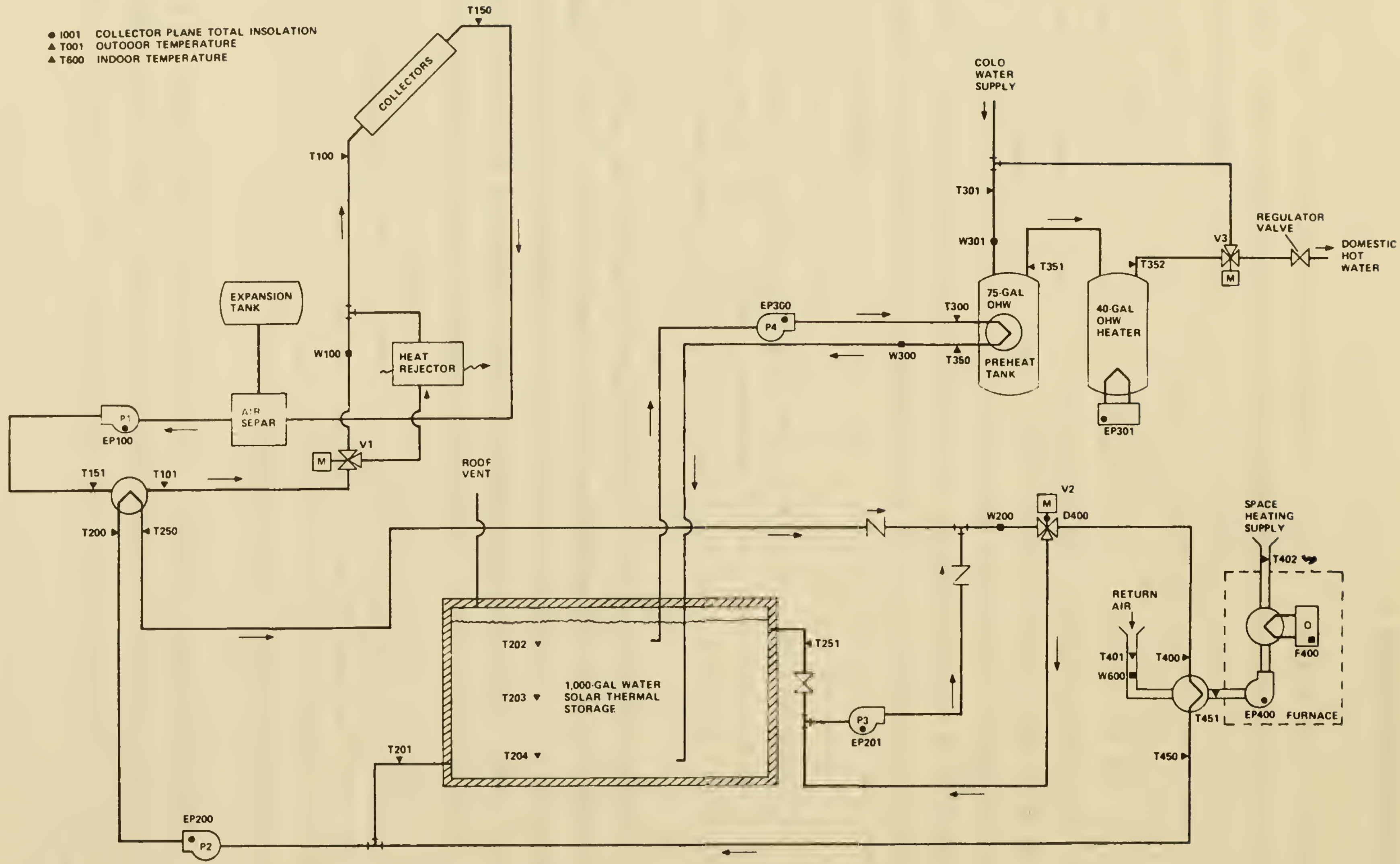

FIGURE 3-1. SOLAR ENERGY SYSTEM SCHEMATIC
STEWART-TEELE-MITCHELL

Mode 4 - Storage-to-DHW Tank: This mode activates when the temperature at the top of the storage tank exceeds the preheat tank water temperature by 10°F. Pump P4 is operating.

Mode 5 - Summer Mode, Collector-to-Vent: This mode activates when the collector array output fluid temperature exceeds 220°F. The collected solar energy is rejected through a fintube heat exchanger located outside the dwelling. Valve V1 directs the collector loop flow through a purge unit.

4. PERFORMANCE EVALUATION TECHNIQUES

The performance of the Stewart-Teele-Mitchell solar energy system is evaluated by calculating a set of primary performance factors which are based on those proposed in the intergovernmental agency report "Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program" [3]. These performance factors quantify the thermal performance of the system by measuring the amount of energies that are being transferred between the components of the system. The performance of the system can then be evaluated based on the efficiency of the system in transferring these energies. All performance factors and their definitions are listed in Appendix A.

Data from monitoring instrumentation located at key points within the solar energy system are collected by the National Solar Data Network. This data is first formed into factors showing the hourly performance of each system component, either by summation or averaging techniques, as appropriate. The hourly factors then serve as a basis for calculating the daily and monthly performance of each component subsystem. The performance factor equations for this site are listed in Appendix B.

Each month, as appropriate, a summary of overall performance of the Stewart-Teele-Mitchell site and a detailed subsystem analysis are published. These monthly reports for the period covered by this Solar Energy System Performance Evaluation November 1978 through March 1979 are available from the Technical Information Center, Oak Ridge, Tennessee 37830.

In the tables and figures in this report, an asterisk indicates that the value is not available for that month; N.A. indicates that the value is not applicable for this site.

5. PERFORMANCE ASSESSMENT

The performance of the Stewart-Teele-Mitchell solar energy system has been evaluated for the November 1978 through March 1979 time period. Two perspectives were taken in this assessment. The first views the overall system in which the total solar energy collected, the system load, the measured values for solar energy used, and system solar fraction are presented. Where applicable, the expected values for solar energy used and system solar fraction are also shown. The expected values have been derived from a modified f-chart analysis which uses measured weather and subsystem loads as input. The f-chart is a performance estimation technique used for designing solar heating systems. It was developed by the Solar Energy Laboratory, University of Wisconsin - Madison. The system mode used in the analysis is based on manufacturer's data and other known system parameters. In addition, the solar energy system coefficient of performance (COP) at both the system and subsystem level has been presented.

The second view presents a more in-depth look at the performance of individual subsystems. Details relating to the performance of the collector array and storage subsystems are presented first, followed by details pertaining to the space heating and domestic hot water (DHW) subsystems. Included in this section are all parameters pertinent to the operation of each individual subsystem.

In addition to the overall system and subsystem analysis, this report also describes the equivalent energy savings contributed by the solar energy system. The overall system and individual subsystem energy savings are presented in Section 5.5.

The performance assessment of any solar energy system is highly dependent on the prevailing weather conditions at the site during the period of performance. The original design of the system is generally based on the long-term averages for available insolation and temperature. Deviations from these long-term averages can significantly affect the performance of the system. Therefore,

before beginning the discussion of actual system performance, a presentation of the measured and long-term averages for critical weather parameters has been provided.

5.1 Weather Conditions

Monthly values of the total solar energy incident in the plane of the collector array and the average outdoor temperature measured at the Stewart-Teele-Mitchell site during the reporting period are presented in Table 5-1. Also presented in Table 5-1 are the corresponding long-term average monthly values of the measured weather parameters. These data are taken from Reference Monthly Environmental Data for Systems in the National Solar Data Network [4]. A complete yearly listing of these values for the site is given in Appendix C.

From November 1978 through March 1979 the average daily total incident solar energy on the collector array was 936 Btu per square foot per day. This was above the estimated average daily solar radiation for this geographical area during the reporting period of 890 Btu per square foot per day for a south-facing plane with a tilt of 45 degrees to the horizontal. The average ambient temperature from November 1978 through March 1979 was 27°F as compared with the long-term average for November through March of 29°F. The number of heating degree-days for the same period (based on a 65°F reference) 5527, as compared with the long-term average of 5465.

Monthly values of heating and cooling degree-days are derived from daily values of ambient temperature. They are useful indications of the system heating and cooling loads. Heating degree-days and cooling degree-days are computed as the difference between daily average temperature and 65°F. For example, if a day's average temperature was 60°F, then five heating degree-days are accumulated. Similarly, if a day's average temperature was 80°F, then 15 cooling degree-days are accumulated. The total number of heating and cooling degree-days is summed monthly.

TABLE 5-1. WEATHER CONDITIONS
STEWART–TEELE–MITCHELL

MONTH	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA[1] (Btu/Ft²)		AMBIENT TEMPERATURE (°F)		HEATING DEGREE-DAYS		COOLING DEGREE-DAYS	
	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE
NOV	886	746	37	40	840	762	0	0
DEC	691	641	27	26	1178	1212	0	0
JAN	454	818	21	22	1361	1349	0	0
FEB	1485	1036	13	24	1308	1162	0	0
MAR	1162	1208	38	33	840	980	0	0
TOTAL					5527	5465	0	0
AVERAGE	936	890	27	29	1105	1093	0	0

[1] In collector array plane and azimuth, unless otherwise indicated in Section 5.1.

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5.2 System Thermal Performance

The thermal performance of a solar energy system is a function of the total solar energy collected and applied to the system load. The total system load is the sum of the useful energy delivered to the loads (excluding losses in the system), both solar and auxiliary thermal energies. The portion of the total load provided by solar energy is defined as the solar fraction of the load.

The thermal performance of the Stewart-Teele-Mitchell solar energy system is presented in Table 5-2. This performance assessment is based on the five-month period from November 1978 to March 1979. During the reporting period, a total of 11.98 million Btu of solar energy was collected and the total system load was 51.40 million Btu. The measured amount of solar energy delivered to the load subsystem(s) was 5.38 million Btu or 11.57 million Btu less than the expected value. The measured system solar fraction was 11 percent as compared to an expected value of 33 percent.

Figure 5-1 illustrates the flow of solar energy from the point of collection to the various points of consumption and loss for the reporting period. The numerical values account for the quantity of energy corresponding with the transport, operation, and function of each major element in the Stewart-Teele-Mitchell solar energy system for the total reporting period.

Solar energy distribution flowcharts for each month of the reporting period are presented in Appendix D.

Table 5-3 summarizes solar energy distribution and provides a percentage breakdown. For the period November 1978 through March 1979, the load subsystems consumed 45 percent of the energy collected and 54 percent was lost. Solar energy storage gain was 1 opercent over the period. Appendix E contains the monthly solar energy percentage distributions.

The solar energy coefficient of performance (COP) is indicated in Table 5-4. The COP simply provides a numerical value for the relationship of solar

TABLE 5-2. SYSTEM THERMAL PERFORMANCE SUMMARY
STEWART–TEELE–MITCHELL

MONTH	SOLAR ENERGY COLLECTED (Million Btu)	SYSTEM LOAD (Million Btu)	SOLAR ENERGY USED (Million Btu)		SOLAR FRACTION (%)	
			EXPECTED	MEASURED	EXPECTED	MEASURED
NOV	1.86	5.17	3.0	0.45	58	9
DEC	2.03	10.37	2.3	1.00	22	10
JAN	0.63	16.97	0.65	0.33	4	1
FEB	3.48	10.38	6.1	1.64	59	13
MAR	3.98	8.51	4.9	1.96	58	19
TOTAL	11.98	51.40	16.95	5.38		
AVERAGE	2.40	10.28	3.39	1.08	33	11

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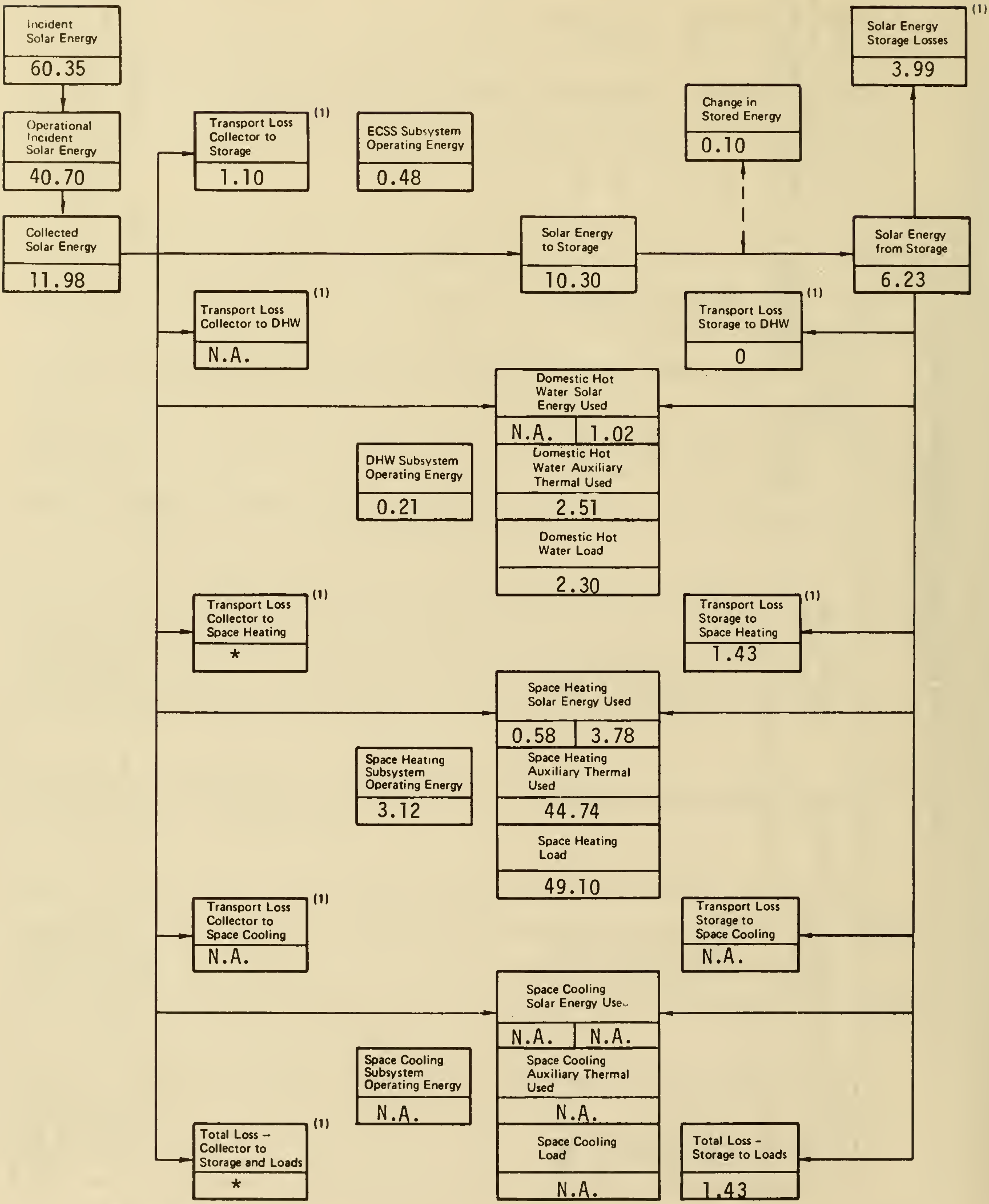
FIGURE 5-1. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - SUMMARY
STEWART-TEELE-MITCHELL



* Denotes Unavailable Data
N.A. denotes not applicable data
(1) May contribute to offset of space heating load (if known – see text for discussion)

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TABLE 5-3. SOLAR ENERGY DISTRIBUTION - SUMMARY NOVEMBER 1978 THROUGH MARCH 1979
STEWART-TEELE-MITCHELL

11.98 million Btu	100%	TOTAL SOLAR ENERGY COLLECTED
5.38 million Btu	45 %	SOLAR ENERGY TO LOADS
1.02 million Btu	9 %	SOLAR ENERGY TO DHW SUBSYSTEM
4.36 million Btu	36 %	SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
N.A. million Btu	%	SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
6.52 million Btu	54 %	SOLAR ENERGY LOSSES
3.99 million Btu	33 %	SOLAR ENERGY LOSS FROM STORAGE
2.53 million Btu	21 %	SOLAR ENERGY LOSS IN TRANSPORT
1.10 million Btu	9 %	COLLECTOR TO STORAGE LOSS
* million Btu	%	COLLECTOR TO LOAD LOSS
N.A. million Btu	%	COLLECTOR TO DHW LOSS
* million Btu	%	COLLECTOR TO SPACE HEATING LOSS
N.A. million Btu	%	COLLECTOR TO SPACE COOLING LOSS
1.43 million Btu	12 %	STORAGE TO LOAD LOSS
* million Btu	%	STORAGE TO DHW LOSS
1.43 million Btu	12 %	STORAGE TO SPACE HEATING LOSS
N.A. million Btu	%	STORAGE TO SPACE COOLING LOSS
.10 million Btu	1 %	SOLAR ENERGY STORAGE CHANGE

* - Denotes unavailable data

N.A. - Denotes not applicable data

TABLE 5-4. SOLAR ENERGY SYSTEM COEFFICIENT OF PERFORMANCE
STEWART-TEELE-MITCHELL

MONTH	SOLAR ENERGY SYSTEM COP	COLLECTOR ARRAY SUBSYSTEM SOLAR COP	DOMESTIC HOT WATER SUBSYSTEM SOLAR COP	SPACE HEATING SUBSYSTEM SOLAR COP	SPACE COOLING SUBSYSTEM SOLAR COP
NOV	1.88	23.25	-	2.81	N.A.
DEC	9.10	25.38	-	34.48	N.A.
JAN	2.75	15.75	2.50	21.67	N.A.
FEB	6.56	26.77	5.50	22.57	N.A.
MAR	7.26	26.53	7.00	27.22	N.A.
WEIGHTED AVERAGE	5.43	24.96	4.86	14.02	N.A.

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N.A. - Denotes not applicable data

energy collected or transported or used and the energy required to perform the transition. The greater the COP value, the more efficient the subsystem. The solar energy system at Stewart-Teele-Mitchell functioned at a weighted average COP value of 5.43 for the reporting period November 1978 through March 1979.

5.3 Subsystem Performance

The Stewart-Teele-Mitchell solar energy installation may be divided into three subsystems:

1. Collector Array and Storage
2. Domestic Hot Water (DHW)
3. Space Heating

Each subsystem is evaluated and analyzed by the techniques defined in Section 4 to produce the monthly performance reports. This section presents the results of integrating the monthly data available on the three subsystems for the period November 1978 through March 1979.

5.3.1 Collector Array and Storage Subsystem

5.3.1.1 Collector Array

Collector array performance for the Stewart-Teele-Mitchell site is presented in Table 5-5. The total incident solar radiation on the collector array for the period November 1978 through March 1979 was 60.35 million Btu. During the period the collector loop was operating the total insolation amounted to 40.70 million Btu. The total collected solar energy for the period was 11.98 million Btu, resulting in a collector array efficiency of 29 percent, based on total incident insolation. Solar energy delivered from the collector array to storage was 10.30 million Btu, while solar energy delivered from the collector array directly to the loads amounted to 0.58 million Btu. Energy loss during transfer from the collector array to storage was 1.10 million

TABLE 5-5. COLLECTOR ARRAY PERFORMANCE
STEWART–TEELE–MITCHELL

MONTH	INCIDENT SOLAR ENERGY (Million Btu)	COLLECTED SOLAR ENERGY (Million Btu)	COLLECTOR ARRAY EFFICIENCY (%)	OPERATIONAL INCIDENT ENERGY (Million Btu)	OPERATIONAL COLLECTOR ARRAY EFFICIENCY (%)
NOV	11.49	1.86	16	6.58	28
DEC	9.26	2.03	22	6.44	32
JAN	6.07	0.63	10	2.40	26
FEB	17.96	3.48	19	13.56	26
MAR	15.57	3.98	26	11.72	34
TOTAL	60.35	11.98		40.70	
AVERAGE	12.07	2.40	20	8.14	29

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Btu. This loss represented 9 percent of the energy collected. Operating energy required by the collector loop was 0.48 million Btu.

Collector array efficiency has been computed from two bases. The first assumes that the efficiency is based upon all available solar energy. This approach makes the operation of the control system part of array efficiency. For example, energy may be available at the collector, but the collector fluid temperature is below the control minimum; therefore, the energy is not collected. In this approach, collector array performance is described by comparing the collected solar energy to the incident solar energy. The ratio of these two energies represents the collector array efficiency which may be expressed as

$$\eta_c = Q_s/Q_i$$

where: η_c = collector array efficiency

Q_s = collected solar energy

Q_i = incident solar energy

The monthly efficiency computed by this method is listed in the column entitled "Collector Array Efficiency" in Table 5-5.

The second approach assumes the efficiency is based upon the incident solar energy during the periods of collection only.

Evaluating collector efficiency using operational incident energy and compensating for the difference between gross collector array area and the gross collector area yield operational collector efficiency. Operational collector efficiency, η_{co}, is computed as follows:

$$\eta_{co} = Q_s/(Q_{oi} \times \frac{A_p}{A_a})$$

where: Q_s = collected solar energy

Q_{oi} = operational incident energy

A_p = gross collector area (product of the number of collectors and the total envelope area of one unit)

A_a = gross collector array area (total area perpendicular to the solar flux vector, including all mounting, connecting and transport hardware

Note: The ratio $\frac{A_p}{A_a}$ is typically 1.0 for most collector array configurations.

The monthly efficiency computed by this method is listed in the column entitled "Operational Collector Array Efficiency" in Table 5-5. This latter efficiency term is not the same as collector efficiency as represented by the ASHRAE Standard 93-77 [5]. Both operational collector efficiency and the ASHRAE collector efficiency are defined as the ratio of actual useful energy collected to solar energy incident upon the collector and both use the same definition of collector area. However, the ASHRAE efficiency is determined from instantaneous evaluation under tightly controlled, steady-state test conditions, while the operational collector efficiency is determined from the actual conditions of daily solar energy system operation. Measured monthly values of operational incident energy and computed values of operational collector efficiency are presented in Table 5-5.

5.3.1.2 Storage

Storage performance data for the Stewart-Teele-Mitchell site for the reporting period is shown in Table 5-6. Results of analysis of solar energy losses during transport and storage are shown in Table 5-7. This table contains an evaluation of solar energy transport losses as a fraction of energy transported to subsystems.

TABLE 5-6. STORAGE PERFORMANCE
STEWART-TEELE-MITCHELL

MONTH	ENERGY TO STORAGE (Million Btu)	ENERGY FROM STORAGE (Million Btu)	CHANGE IN STORED ENERGY (Million Btu)	STORAGE EFFICIENCY (%)	STORAGE AVERAGE TEMPERATURE (°F)	EFFECTIVE STORAGE HEAT LOSS COEFFICIENT (Btu/Hr -- °F)
NOV	1.60	0.56	0.08	40	110	*
DEC	1.69	1.09	-0.07	60	94	*
JAN	0.58	0.33	-0.13	35	78	*
FEB	3.00	1.81	0.21	67	88	*
MAR	3.43	2.44	-0.01	71	102	*
TOTAL	10.30	6.23	0.10			
AVERAGE	2.06	1.25	.02	61	94	*

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* - Denotes unavailable data
(1) - Weighted average

TABLE 5-7. SOLAR ENERGY LOSSES – STORAGE AND TRANSPORT
STEWART–TEELE–MITCHELL

	MONTH							TOTAL
	NOV	DEC	JAN	FEB	MAR			
1. SOLAR ENERGY (SE) COLLECTED MINUS SE DIRECTLY TO LOADS (million Btu)	1.77	1.85	0.61	3.27	3.90			11.40
2. SE TO STORAGE (million Btu)	1.60	1.69	0.58	3.00	3.43			10.30
3. LOSS – COLLECTOR TO STORAGE (%) $\frac{1-2}{1}$	10	9	5	8	12			10
4. CHANGE IN STORED ENERGY (million Btu)	0.08	-0.07	-0.13	0.21	-0.01			0.10
5. SOLAR ENERGY – STORAGE TO DHW SUBSYSTEM (million Btu)	0	0	0.20	0.33	0.49			1.02
6. SOLAR ENERGY – STORAGE TO SPACE HEATING SUBSYSTEM (million Btu)	0.56	1.09	0.13	1.48	1.95			5.21
7. SOLAR ENERGY – STORAGE TO SPACE COOLING SUBSYSTEM (million Btu)	N.A.	N.A.	N.A.	N.A.	N.A.			N.A.
8. LOSS FROM STORAGE (%) $\frac{2-(4+5+6+7)}{2}$	60	40	66	33	29			39
9. HOT WATER SOLAR ENERGY (HWSE) FROM STORAGE (million Btu)	0	0	0.20	0.33	0.49			1.02
10. LOSS – STORAGE TO HWSE (%) $\frac{5-9}{5}$	0	0	0	0	0			0
11. HEATING SOLAR ENERGY (HSE) FROM STORAGE (million Btu)	0.36	0.82	0.11	1.10	1.39			3.78
12. LOSS – STORAGE TO HSE (%) $\frac{6-11}{6}$	36	25	15	26	29			27

S002

* - Denotes unavailable data
N.A. - Denotes not applicable data

During the reporting period, total solar energy delivered to storage was 10.30 million Btu. There were 6.23 million Btu delivered from storage to the DHW and space heating subsystems. Energy loss from storage was 3.99 million Btu. This loss represented 39 percent of the energy delivered to storage. The storage efficiency was 61 percent: This is calculated as the ratio of the sum of the energy removed from storage and the change in stored energy, to the energy delivered to storage. The average storage temperature for the period was 94°F.

Storage subsystem performance is evaluated by comparison of energy to storage, energy from storage and the change in stored energy. The ratio of the sum of energy from storage and the change in stored energy, to the energy to storage is defined as storage efficiency, η_s. This relationship is expressed in the equation

$$\eta_s = (\Delta Q + Q_{so})/Q_{si}$$

where:

ΔQ = change in stored energy. This is the difference in the estimated stored energy during the specified reporting period, as indicated by the relative temperature of the storage medium (either positive or negative value)

Q_{so} = energy from storage. This is the amount of energy extracted by the load subsystem from the primary storage medium

Q_{si} = energy to storage. This is the amount of energy (both solar and auxiliary) delivered to the primary storage medium

5.3.2 Domestic Hot Water (DHW) Subsystem

The DHW subsystem performance for the Stewart-Teele-Mitchell site for the reporting period is shown in Table 5-8. The DHW subsystem consumed 1.02 million Btu of solar energy and 2.51 million Btu of auxiliary electrical energy to satisfy a hot water load of 2.30 million Btu. The solar fraction of this load was 13 percent.

The performance of the DHW subsystem is described by comparing the amount of solar energy supplied to the subsystem with the total energy required by the subsystem. The total energy required by the subsystem consists of both solar energy and auxiliary thermal energy. The DHW load is defined as the amount of energy required to raise the mass of water delivered by the DHW subsystem between the temperature at which it entered the subsystem and its delivery temperature. The DHW solar fraction is defined as the portion of the DHW load which is supported by solar energy.

5.3.3 Space Heating Subsystem

The space heating subsystem performance for the Stewart-Teele-Mitchell site for the reporting period is shown in Table 5-9. The space heating subsystem consumed 4.36 million Btu of solar energy and 69.17 million Btu of auxiliary fossil fuel energy to satisfy a space heating load of 49.10 million Btu. The solar fraction of this load was 9 percent.

The performance of the space heating subsystem is described by comparing the amount of solar energy supplied to the subsystem with the energy required to satisfy the total space heating load. The energy required to satisfy the total load consists of both solar energy and auxiliary thermal energy. The ratio of solar energy supplied to the load to the total load is defined as the heating solar fraction.

TABLE 5-8. DOMESTIC HOT WATER SUBSYSTEM PERFORMANCE
STEWART-TEELE-MITCHELL

MONTH	DOMESTIC HOT WATER LOAD (Million Btu)	ENERGY CONSUMED (Million Btu)				SOLAR FRACTION (%)
		SOLAR	AUXILIARY THERMAL	AUXILIARY		
				ELECTRICAL	FOSSIL	
NOV	0.02	0	0.26	0.26	N.A.	0
DEC	0.55	0	0.73	0.73	N.A.	0
JAN	0.59	0.20	0.60	0.60	N.A.	9
FEB	0.52	0.33	0.47	0.47	N.A.	13
MAR	0.62	0.49	0.45	0.45	N.A.	24
TOTAL	2.30	1.02	2.51	2.51	N.A.	
AVERAGE	0.46	0.20	0.50	0.50	N.A.	13

N.A. - Denotes not applicable data

S002

TABLE 5-9 SPACE HEATING SUBSYSTEM PERFORMANCE
STEWART–TEELE–MITCHELL

MONTH	SPACE HEATING LOAD (Million Btu)	ENERGY CONSUMED (Million Btu)				SOLAR FRACTION (%)
		SOLAR	AUXILIARY THERMAL	AUXILIARY		
				ELECTRICAL	FOSSIL	
NOV	5.15	0.45	4.70	N.A.	7.84	9
DEC	9.82	1.00	8.81	N.A.	14.69	10
JAN	16.38	0.13	16.25	N.A.	23.21	1
FEB	9.86	1.31	8.55	N.A.	14.25	13
MAR	7.89	1.47	6.43	N.A.	9.18	19
TOTAL	49.10	4.36	44.74	N.A.	69.17	
AVERAGE	9.82	0.87	8.95	N.A.	13.83	9

N.A. - Denotes not applicable data

S002

5.4 Operating Energy

Measured values of the Stewart-Teele-Mitchell solar energy system and subsystem operating energy for the reporting period are presented in Table 5-10. A total of 3.80 million Btu of operating energy was consumed by the entire system during the reporting period.

Operating energy for a solar energy system is defined as the amount of electrical energy required to support the subsystems without affecting their thermal state.

Total system operating energy for Stewart-Teele-Mitchell is the energy required to support the energy collection and storage subsystem (ECSS), the DHW subsystem and the space heating subsystem. With reference to the system schematic (Figure 3-1), the ECSS operating energy includes pumps P1 (EP100) and P2 (EP200). One hundred percent of the operating energy of pumps P1 and P2 is assigned to the Ecss when the sytem is in the collector to storage mode and 75 percent is assigned when the system is in the collector to space heating mode. The DHW subsystem operating energy consists of pump P4 (EP300). The space heating subsystem operating energy consists of pump P3 (EP201, and blower (EP400). Additionally, 25 percent of the operating energy of pumps P1 (EP100) and P2 (EP200) is assigned to the space heating subsystem when the system is in the collector-to-space heating mode.

5.5 Energy Savings

Energy savings for the Stewart-Teele-Mitchell site for the reporting period are presented in Table 5-11. For this period the total savings of electrical energy were 0.71 million Btu for a monthly average of 0.14 million Btu; total savings of fossil fuel energy were 7.25 million Btu, for a monthly average of 1.45 million Btu. An electrical energy expense of 0.99 million Btu was incurred during the reporting period for the operation of solar energy transportation pumps.

TABLE 5-10. OPERATING ENERGY
STEWART-TEELE-MITCHELL

MONTH	ENERGY COLLECTION AND STORAGE OPERATING ENERGY (Million Btu)	DOMESTIC HOT WATER OPERATING ENERGY (Million Btu)	SPACE HEATING OPERATING ENERGY (Million Btu)	SPACE COOLING OPERATING ENERGY (Million Btu)	TOTAL SYSTEM OPERATING ENERGY (Million Btu)
NOV	0.08	0	0.90	N.A.	0.98
DEC	0.08	0	0.63	N.A.	0.71
JAN	0.04	0.08	0.61	N.A.	0.73
FEB	0.13	0.06	0.62	N.A.	0.81
MAR	0.15	0.07	0.35	N.A.	0.57
TOTAL	0.48	0.21	3.11	N.A.	3.80
AVERAGE	0.10	0.04	0.62	N.A.	0.76

N.A. - Denotes not applicable data

S002

TABLE 5-11. ENERGY SAVINGS
STEWART-TEELE-MITCHELL

MONTH	SOLAR ENERGY USED (Million Btu)	SOLAR ENERGY SAVINGS ATTRIBUTED TO (Million Btu)						SOLAR OPERATING ENERGY (Million Btu)	ENERGY SAVINGS (Million Btu)	
		SPACE HEATING		DOMESTIC HOT WATER		SPACE COOLING				
		ELECTRICAL	FOSSIL FUEL	ELECTRICAL	FOSSIL FUEL	ELECTRICAL	FOSSIL FUEL		ELECTRICAL	FOSSIL FUEL
NOV	0.45	-0.16	0.74	0	0	N.A.	N.A.	0.24	-0.24	0.74
DEC	1.00	-0.03	1.67	0	0	N.A.	N.A.	0.11	-0.11	1.67
JAN	0.33	-0.01	0.22	-0.02	N.A.	N.A.	N.A.	0.12	-0.06	0.22
FEB	1.64	-0.06	2.18	0.02	N.A.	N.A.	N.A.	0.25	-0.17	2.18
MAR	1.96	-0.05	2.44	0.07	N.A.	N.A.	N.A.	0.27	-0.13	2.44
TOTAL	5.38	0.31	7.25	0.07	N.A.	N.A.	N.A.	0.99	-0.71	7.25
AVERAGE	1.08	0.06	1.45	0.01	N.A.	N.A.	N.A.	0.20	-0.14	1.45

N.A. - Denotes not applicable data

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Solar energy system savings are realized whenever energy provided by the solar energy system is used to meet system demands which would otherwise be met by auxiliary energy sources. The operating energy required to provide solar energy to the load subsystems is subtracted from the solar energy contribution to determine net savings.

The auxiliary source at Stewart-Teele-Mitchell consists of an oil-fired furnance for space heating and an electrical DHW heater. The units are considered to be 70 and 100 percent efficient for computational purposes.

6. REFERENCES

1. U.S. Department of Energy, National Solar Data Network, prepared under contract number EG-77-C-4049 by IBM Corporation, December 1977.

2. J. T. Smok, V. S. Sohoni, J. M. Nash, "Processing of Instrumented Data for the National Solar Heating and Cooling Demonstration Program," Conference on Performance Monitoring Techniques for Evaluation of Solar Heating and Cooling Systems, Washington, D.C., April 1978.

3. E. Streed, et. al., Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program, NBSIR-76-1137, National Bureau of Standards, Washington, D.C., 1976.

4. Mears, J. C. Reference Monthly Environmental Data for Systems in the National Solar Data Network. Department of Energy report SOLAR/0019-79/36. Washington, D.C., 1979.

5. ASHRAE Standard 93-77, Methods of Testing to Determine the Thermal Performance of Solar Collectors, The American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc., New York, N.Y., 1977.

6.# Monthly Performance Report, Stewart-Teele-Mitchell, SOLAR/1018-78/11, Department of Energy, Washington, D.C., (November 1978).

7.# Monthly Performance Report, Stewart-Teele-Mitchell, SOLAR/1018-78/12, Department of Energy, Washington, D.C., (December 1978).

8.# Monthly Performance Report, Stewart-Teele-Mitchell, SOLAR/1018-79/01, Department of Energy, Washington, D.C., (January 1979).

9.# Monthly Performance Report, Stewart-Teele-Mitchell, SOLAR/1018-79/02, Department of Energy, Washington, D.C., (February 1979).

10.# Monthly Performance Report, Stewart-Teele-Mitchell, SOLAR/1018-79/03, Department of Energy, Washington, D.C., (March 1979).

#Copies of these reports may be obtained from Technical Information Center, P. O. Box 62, Oak Ridge, Tennessee 37830.

APPENDIX A

DEFINITIONS OF PERFORMANCE FACTORS AND SOLAR TERMS

COLLECTOR ARRAY PERFORMANCE

The collector array performance is characterized by the amount of solar energy collected with respect to the energy available to be collected.

- INCIDENT SOLAR ENERGY (SEA) is the total insolation available on the gross collector array area. This is the area of the collector array energy-receiving aperture, including the framework which is an integral part of the collector structure.

- OPERATIONAL INCIDENT ENERGY (SEOP) is the amount of solar energy incident on the collector array during the time that the collector loop is active (attempting to collect energy).

- COLLECTED SOLAR ENERGY (SECA) is the thermal energy removed from the collector array by the energy transport medium.

- COLLECTOR ARRAY EFFICIENCY (CAREF) is the ratio of the energy collected to the total solar energy incident on the collector array. It should be emphasized that this efficiency factor is for the collector array, and available energy includes the energy incident on the array when the collector loop is inactive. This efficiency must not be confused with the more common collector efficiency figures which are determined from instantaneous test data obtained during steady-state operation of a single collector unit. These efficiency figures are often provided by collector manufacturers or presented in technical journals to characterize the functional capability of a particular collector design. In general, the collector panel maximum efficiency factor will be significantly higher than the collector array efficiency reported here.

STORAGE PERFORMANCE

The storage performance is characterized by the relationships among the energy delivered to storage, removed from storage, and the subsequent change in the amount of stored energy.

- ENERGY TO STORAGE (STEI) is the amount of energy, both solar and auxiliary, delivered to the primary storage medium.

- ENERGY FROM STORAGE (STEO) is the amount of energy extracted by the load subsystems from the primary storage medium.

- CHANGE IN STORED ENERGY (STECH) is the difference in the estimated stored energy during the specified reporting period, as indicated by the relative temperature of the storage medium (either positive or negative value).

- STORAGE AVERAGE TEMPERATURE (TST) is the mass-weighted average temperature of the primary storage medium.

- STORAGE EFFICIENCY (STEFF) is the ratio of the sum of the energy removed from storage and the change in stored energy to the energy delivered to storage.

ENERGY COLLECTION AND STORAGE SUBSYSTEM

The Energy Collection and Storage Subsystem (ECSS) is composed of the collector array, the primary storage medium, the transport loops between these, and other components in the system design which are necessary to mechanize the collector and storage equipment.

- INCIDENT SOLAR ENERGY (SEA) is the total insolation available on the gross collector array area. This is the area of the collector array energy-receiving aperture, including the framework which is an integral part of the collector structure.

- AMBIENT TEMPERATURE (TA) is the average temperature of the outdoor environment at the site.

- ENERGY TO LOADS (SEL) is the total thermal energy transported from the ECSS to all load subsystems.

- AUXILIARY THERMAL ENERGY TO ECSS (CSAUX) is the total auxiliary energy supplied to the ECSS, including auxiliary energy added to the storage tank, heating devices on the collectors for freeze-protection, etc.

- ECSS OPERATING ENERGY (CSOPE) is the critical operating energy required to support the ECSS heat transfer loops.

HOT WATER SUBSYSTEM

The hot water subsystem is characterized by a complete accounting of the energy flow into and from the subsystem, as well as an accounting of internal energy. The energy into the subsystem is composed of auxiliary fossil fuel, and electrical auxiliary thermal energy, and the operating energy for the subsystem.

- HOT WATER LOAD (HWL) is the amount of energy required to heat the amount of hot water demanded at the site from the incoming temperature to the desired outlet temperature.

- SOLAR FRACTION OF LOAD (HWSFR) is the percentage of the load demand which is supported by solar energy.

- SOLAR ENERGY USED (HWSE) is the amount of solar energy supplied to the hot water subsystem.

- OPERATING ENERGY (HWOPE) is the amount of electrical energy required to support the subsystem, (e.g., fans, pumps, etc.) and which is not intended to directly affect the thermal state of the subsystem.

- AUXILIARY THERMAL USED (HWAT) is the amount of energy supplied to the major components of the subsystem in the form of thermal energy in a heat transfer fluid, or its equivalent. This term also includes the converted electrical and fossil fuel energy supplied to the subsystem.

- AUXILIARY FOSSIL FUEL (HWAF) is the amount of fossil fuel energy supplied directly to the subsystem.

- ELECTRICAL ENERGY SAVINGS (HWSVE) is the estimated difference between the electrical energy requirements of an alternative conventional system (carrying the full load) and the actual electrical energy required by the subsystem.

- FOSSIL FUEL SAVINGS (HWSVF) is the estimated difference between the fossil fuel energy requirements of the alternative conventional system (carrying the full load) and the actual fossil fuel energy requirements of the subsystem.

SPACE HEATING SUBSYSTEM

The space heating subsystem is characterized by performance factors accounting for the complete energy flow into the subsystem. The average building temperature is tabulated to indicate the relative performance of the subsystem in satisfying the space heating load and in controlling the temperature of the conditioned space.

- SPACE HEATING LOAD (HL) is the sensible energy added to the air in the building.

- SOLAR FRACTION OF LOAD (HSFR) is the fraction of the sensible energy added to the air in the building derived from the solar energy system.

- SOLAR ENERGY USED (HSE) is the amount of solar energy supplied to the space heating subsystem.

- <u>OPERATING ENERGY</u> (HOPE) is the amount of electrical energy required to support the subsystem, (e.g., fans, pumps, etc.) and which is not intended to directly affect the thermal state of the system.

- <u>AUXILIARY THERMAL USED</u> (HAT) is the amount of energy supplied to the major components of the subsystem in the form of thermal energy in a heat transfer fluid or its equivalent. This term also includes the converted electrical and fossil fuel energy supplied to the subsystem.

- <u>AUXILIARY ELECTRICAL FUEL</u> (HAE) is the amount of electrical energy supplied directly to the subsystem.

- <u>ELECTRICAL ENERGY SAVINGS</u> (HSVE) is the estimated difference between the electrical energy requirements of an alternative conventional system (carrying the full load) and the actual electrical energy required by the subsystem.

- <u>BUILDING TEMPERATURE</u> (TB) is the average heated space dry bulb temperature.

APPENDIX B

SOLAR ENERGY SYSTEM PERFORMANCE EQUATIONS

STEWART-TEELE-MITCHELL

INTRODUCTION

Solar energy system performance is evaluated by performing energy balance calculations on the system and its major subsystems. These calculations are based on physical measurement data taken from each sensor every 320 seconds. This data is then mathematically combined to determine the hourly, daily, and monthly performance of the system. This appendix describes the general computational methods and the specific energy balance equations used for this site.

Data samples from the system measurements are integrated to provide discrete approximations of the continuous functions which characterize the system's dynamic behavior. This integration is performed by summation of the product of the measured rate of the appropriate performance parameters and the sampling interval over the total time period of interest.

There are several general forms of integration equations which are applied to each site. These general forms are exemplified as follows: The total solar energy available to the collector array is given by

$$\text{SOLAR ENERGY AVAILABLE} = (1/60)\ \Sigma\ [\text{I001} \times \text{AREA}] \times \Delta\tau$$

where I001 is the solar radiation measurement provided by the pyranometer in Btu per square foot per hour, AREA is the area of the collector array in square feet, $\Delta\tau$ is the sampling interval in minutes, and the factor (1/60) is included to correct the solar radiation "rate" to the proper units of time.

Similarly, the energy flow within a system is given typically by

$$\text{COLLECTED SOLAR ENERGY} = \Sigma\ [\text{M100} \times \Delta H] \times \Delta\tau$$

where M100 is the mass flow rate of the heat transfer fluid in lb_m/min and ΔH is the enthalpy change, in Btu/lb_m, of the fluid as it passes through the heat exchanging component.

For a liquid system ΔH is generally given by

$$\Delta H = \overline{C}_p\ \Delta T$$

where $\overline{C}_p$ is the average specific heat, in Btu/(lb_m-°F), of the heat transfer fluid and ΔT, in °F, is the temperature differential across the heat exchanging component.

For an air system ΔH is generally given by

$$\Delta H = H_a(T_{out}) - H_a(T_{in})$$

where $H_a(T)$ is the enthalpy, in Btu/lb_m, of the transport air evaluated at the inlet and outlet temperatures of the heat exchanging component.

$H_a(T)$ can have various forms, depending on whether or not the humidity ratio of the transport air remains constant as it passes through the heat exchanging component.

For electrical power, a general example is

$$\text{ECSS OPERATING ENERGY} = (3413/60)\ \Sigma\ [\text{EP100}] \times \Delta\tau$$

where EP100 is the power required by electrical equipment in kilowatts and the two factors (1/60) and 3413 correct the data to Btu/min.

These equations are comparable to those specified in "Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program." This document was prepared by an interagency committee of the Government, and presents guidelines for thermal performance evaluation.

Performance factors are computed for each hour of the day. Each integration process, therfore, is performed over a period of one hour. Since long-term performance data is desired, it is necessary to build these hourly performance factors to daily values. This is accomplished, for energy parameters, by summing the 24 hourly values. For temperatures, the hourly values are averaged. Certain special factors, such as efficiencies, require appropriate handling to properly weight each hourly sample for the daily value computation. Similar procedures are required to convert daily values to monthly values.

EQUATIONS USED TO GENERATE MONTHLY PERFORMANCE VALUES

NOTE: SENSOR IDENTIFICATION (MEASUREMENT) NUMBERS REFERENCE SYSTEM SCHEMATIC FIGURE 3-1

AVERAGE AMBIENT TEMPERATURE (°F)

$$TA = (1/60) \times \Sigma\ T001 \times \Delta\tau$$

AVERAGE BUILDING TEMPERATURE (°F)

$$TB = (1/60) \times \Sigma\ T600 \times \Delta\tau$$

DAYTIME AVERAGE AMBIENT TEMPERATURE (°F)

$$TDA = (1/360) \times \Sigma\ T001 \times \Delta\tau$$

FOR $\pm$ 3 HOURS FROM SOLAR NOON

INCIDENT SOLAR ENERGY PER SQUARE FOOT (BTU/FT^2)

$$SE = (1/60) \times \Sigma\ I001 \times \Delta\tau$$

OPERATION INCIDENT SOLAR ENERGY (BTU)

$$SEOP = (1/60) \times \Sigma\ [I001 \times CLAREA] \times \Delta\tau$$

WHEN THE COLLECTOR LOOP IS ACTIVE

HUMIDITY RATIO FUNCTION (BTU/lb_m - °F)

$$HRF = 0.24 + 0.44 \times HR$$

WHERE 0.24 IS THE SPECIFIC HEAT AND HR IS THE HUMIDITY RATIO OF THE TRANSPORT AIR. THIS FUNCTION IS USED WHENEVER THE HUMIDITY RATIO WILL REMAIN CONSTANT AS THE TRANSPORT AIR FLOWS THROUGH A HEAT EXCHANGING DEVICE.

COLLECTED SOLAR ENERGY (BTU/FT^2)

$$SEC - SECA/CLAREA$$

ECSS OPERATING ENERGY (BTU)

$$CSOPE = CSOPE1 + CSOPE2$$

WHERE $CSOPE1 = 56.8833 \times \Sigma\ (EP100 + EP200) \times \Delta\tau$
WHEN SYSTEM IS IN THE COLLECTOR-TO-STORAGE MODE AND
$CSOPE2 = 56.8833 \times 0.75 \times \Sigma\ (EP100 + EP200) \times \Delta\tau$
WHEN SYSTEM IS IN THE COLLECTOR-TO-SPACE HEATING MODE

ECSS SOLAR CONVERSION EFFICIENCY

$$CSCEF = CSEO/SEA$$

COLLECTOR ARRAY EFFICIENCY

$$CAREF = SECA/SEA$$

SOLAR ENERGY COLLECTED BY THE ARRAY (BTU)

$$SECA = \Sigma\ [M100 \times CP17\ (T100 + T150)/2 \times (T150 - T100)] \times \Delta\tau$$

WHERE CP17 IDENTIFIES THE SPECIFIC HEAT OF THE 40% BY VOLUME SOLUTION OF ETHYLENE-GLYCOL IN WATER USED AS THE HEAT TRANSFER MEDIUM

SOLAR ENERGY TO STORAGE (BTU)

$$STEI = \Sigma\ [M200 \times HWD\ (T251,\ T201)] \times \Delta\tau$$

SOLAR ENERGY FROM STORAGE (BTU)

$$STEO = STEOHC + HWSE$$

WHERE $STEOHC = \Sigma\ [M200 \times HWD\ (T251,\ T201)] \times \Delta\tau$

WHEN SYSTEM IS IN THE STORAGE-TO-SPACE HEATING MODE

AVERAGE TEMPERATURE OF STORAGE (BTU)

$$TST = (1/60) \times \Sigma\ [(T202 + T203 + T204)/3] \times \Delta\tau$$

CHANGE IN STORED ENERGY (BTU)

$$STECH = STOCAP \times (STECH1 - STECH1_p)$$

WHERE THE SUBSCRIPT $_p$ REFERS TO A PRIOR REFERENCE VALUE

STORAGE EFFICIENCY

$$STEFF = (STECH + STEO)/STEI$$

SPACE HEATING SUBSYSTEM OPERATING ENERGY (BTU)

$$HOPE = HOPE1 + HOPE2 + HOPE3$$

WHERE $HOPE1 = 56.8833 \times \Sigma\ EP201 \times \Delta\tau$

WHEN SYSTEM IS IN THE STORAGE-TO-SPACE HEATING MODE

$$HOPE2 = 56.8833 \times 0.25 \times \Sigma\ (EP100 + EP200) \times \Delta\tau$$

WHEN SYSTEM IS IN THE COLLECTOR-TO-SPACE HEATING MODE

$$HOPE3 = 56.8833 \times \Sigma\ EP400 \times \Delta\tau$$

ENERGY DELIVERED FROM ECSS TO LOAD (BTU)

$$CSEO = STEO + HSE2$$

WHERE HSE2 IS THE ENERGY DELIVERED TO THE SPACE HEATING LOAD WHEN THE SYSTEM IS IN THE COLLECTOR-TO-SPACE HEATING MODE

SOLAR ENERGY TO SPACE HEATING SUBSYSTEM (BTU)

$$HSE = HSE1 + HSE2$$

WHERE $HSE1 = \Sigma\ [M201 \times HWD\ (T400, T450)] \times \Delta\tau$

WHEN SYSTEM IS IN THE STORAGE-TO-SPACE HEATING MODE

$$HSE2 = \Sigma\ [M204 \times HWD\ (T400, T450)] \times \Delta\tau$$

WHEN THE SYSTEM IS IN THE COLLECTOR-TO-SPACE HEATING MODE

SPACE HEATING SUBSYSTEM LOAD (BTU)

$$HL = HAT + HSE$$

SPACE HEATING SUBSYSTEM AUXILIARY THERMAL ENERGY (BTU)

$$HAT = 140{,}000 \times 0.7 \times (1/60)\ \Sigma\ F400 \times \Delta\tau$$

SPACE HEATING SUBSYSTEM AUXILIARY FOSSIL FUEL ENERGY (BTU)

$$HAF = HAT/0.7$$

SPACE HEATING SUBSYSTEM ELECTRICAL ENERGY SAVINGS (BTU)

$$HSVE = -\ (HOPE1 + HOPE2)$$

SPACE HEATING SUBSYSTEM FOSSIL FUEL ENERGY SAVINGS (BTU)

$$HSVF = HSE/0.6$$

SPACE HEATING SUBSYSTEM SOLAR FRACTION (PERCENT)

$$HSFR = 100 \times HSE/HL$$

SOLAR ENERGY TO DHW SUBSYSTEM (BTU)

$$HWSE = \Sigma\ [M300 \times HWD\ (T300, T350)] \times \Delta\tau$$

DHW SUBSYSTEM LOAD (BTU)

$$HWL = \Sigma\ [M301 \times HWD\ (T352,\ T301)] \times \Delta\tau$$

DHW SUBSYSTEM OPERATING ENERGY (BTU)

$$HWOPE = 56.8833 \times \Sigma\ EP300 \times \Delta\tau$$

DHW SUBSYSTEM AUXILIARY FUEL ENERGY (BTU)

$$HWAE = 56.8833 \times \Sigma\ EP301 \times \Delta\tau$$

DHW SUBSYSTEM AUXILIARY THERMAL ENERGY (BTU)

$$HWAT = HWAE$$

DHW SUBSYSTEM SOLAR FRACTION (PERCENT)

$$HWSFR = 100 \times HWTKSE/(HWTKSE + HWTKAUX)$$

WHERE HWTKSE IS THE ENERGY IN THE DHW TANK ATTRIBUTABLE TO SOLAR AND HWTKAUX IS THE ENERGY IN THE DHW TANK ATTRIBUTABLE TO AUXILIARY AT ANY GIVEN TIME

DHW SUBSYSTEM ELECTRICAL ENERGY SAVINGS (BTU)

$$HWSVE = \Sigma\ [M301 \times (T351,\ T301)] \times \Delta\tau - HWOPE$$

SERVICE SUPPLY WATER TEMPERATURE (°F)

$$TSW = (1/60) \times \Sigma\ T301 \times \Delta\tau$$

WHEN WATER IS BEING DRAWN

SERVICE HOT WATER TEMPERATURE (°F)

$$THW = (1/60) \times \Sigma\ T352 \times \Delta\tau$$

WHEN WATER IS BEING DRAWN

HOT WATER CONSUMED (GALLONS)

$$HWCSM = W301$$

WHERE W301 IS A TOTALIZING WATER METER WITH RANGE 0 TO 100 GALLONS

TOTAL ENERGY CONSUMED (BTU)

$$TECSM = SYSOPE + AXE + SECA + AXF$$

SYSTEM OPERATING ENERGY (BTU)

SYSOPE = HOPE + CSOPE + HWOPE

SYSTEM LOAD (BTU)

SYSL = HWL + HL

SOLAR ENERGY TO LOAD SUBSYSTEMS (BTU)

SEL = HWSE + HSE

SOLAR FRACTION OF SYSTEM LOAD

SFR = (HWSFR x HWL + HSFR x HL)/SYSL

AUXILIARY THERMAL ENERGY TO LOADS (BTU)

AXT = HWAT + HAT

AUXILIARY ELECTRICAL ENERGY TO LOADS (BTU)

AXE = HWAE

AUXILIARY FOSSIL FUEL ENERGY TO LOADS (BTU)

AXF = HAF

TOTAL ELECTRICAL ENERGY SAVINGS

TSVE = HWSVE + HSVE - CSOPE

TOTAL FOSSIL FUEL ENERGY SAVINGS

TSVF = HSVF

SYSTEM PERFORMANCE FACTOR

SYSPF = SYSL/[AXF + 3.33 x (AXE + SYSOPE)]

APPENDIX C

LONG-TERM AVERAGE WEATHER CONDITIONS

This appendix contains a table which lists the long-term average weather conditions for each month of the year for this site.

SITE: STEW-TEELE-MIT 62. LOCATION: MALTA NY

ANALYST: J. HUGHES FDRIVE NO.: 30.

COLLECTOR TILT: 45.00 (DEGREES) COLLECTOR AZIMUTH: 0.0 (DEGREES)

LATITUDE: 43.00 (DEGREES) RUN DATE: 6/04/79

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
JAN	1165.	457.	0.39233	1.788	818.	1349	0	22.
FEB	1640.	689.	0.42046	1.502	1036.	1162	0	24.
MAR	2270.	984.	0.43372	1.227	1208.	980	0	33.
APR	2945.	1335.	0.45316	1.015	1355.	543	0	47.
MAY	3437.	1571.	0.45697	0.890	1398.	253	27	58.
JUN	3643.	1729.	0.47466	0.840	1453.	39	114	68.
JUL	3536.	1726.	0.48796	0.861	1486.	9	226	72.
AUG	3132.	1501.	0.47906	0.960	1441.	22	165	70.
SEP	2511.	1169.	0.46547	1.144	1337.	135	42	62.
OCT	1822.	819.	0.44914	1.424	1165.	422	0	51.
NOV	1275.	457.	0.35855	1.631	746.	762	0	40.
DEC	1038.	353.	0.34443	1.793	641.	1212	0	26.

LEGEND:

HOBAR ==> MONTHLY AVERAGE DAILY EXTRATERRESTRIAL RADIATION (IDEAL) IN BTU/DAY-FT2.

HBAR ==> MONTHLY AVERAGE DAILY RADIATION (ACTUAL) IN BTU/DAY-FT2.

KBAR ==> RATIO OF HBAR TO HOBAR.

RBAR ==> RATIO OF MONTHLY AVERAGE DAILY RADIATION ON TILTED SURFACE TO THAT ON A HORIZONTAL SURFACE FOR EACH MONTH (I.E., MULTIPLIER OBTAINED BY TILTING).

SBAR ==> MONTHLY AVERAGE DAILY RADIATION ON A TILTED SURFACE (I.E., RBAR * HBAR) IN BTU/DAY-FT2.

HDD ==> NUMBER OF HEATING DEGREE DAYS PER MONTH.

CDD ==> NUMBER OF COOLING DEGREE DAYS PER MONTH.

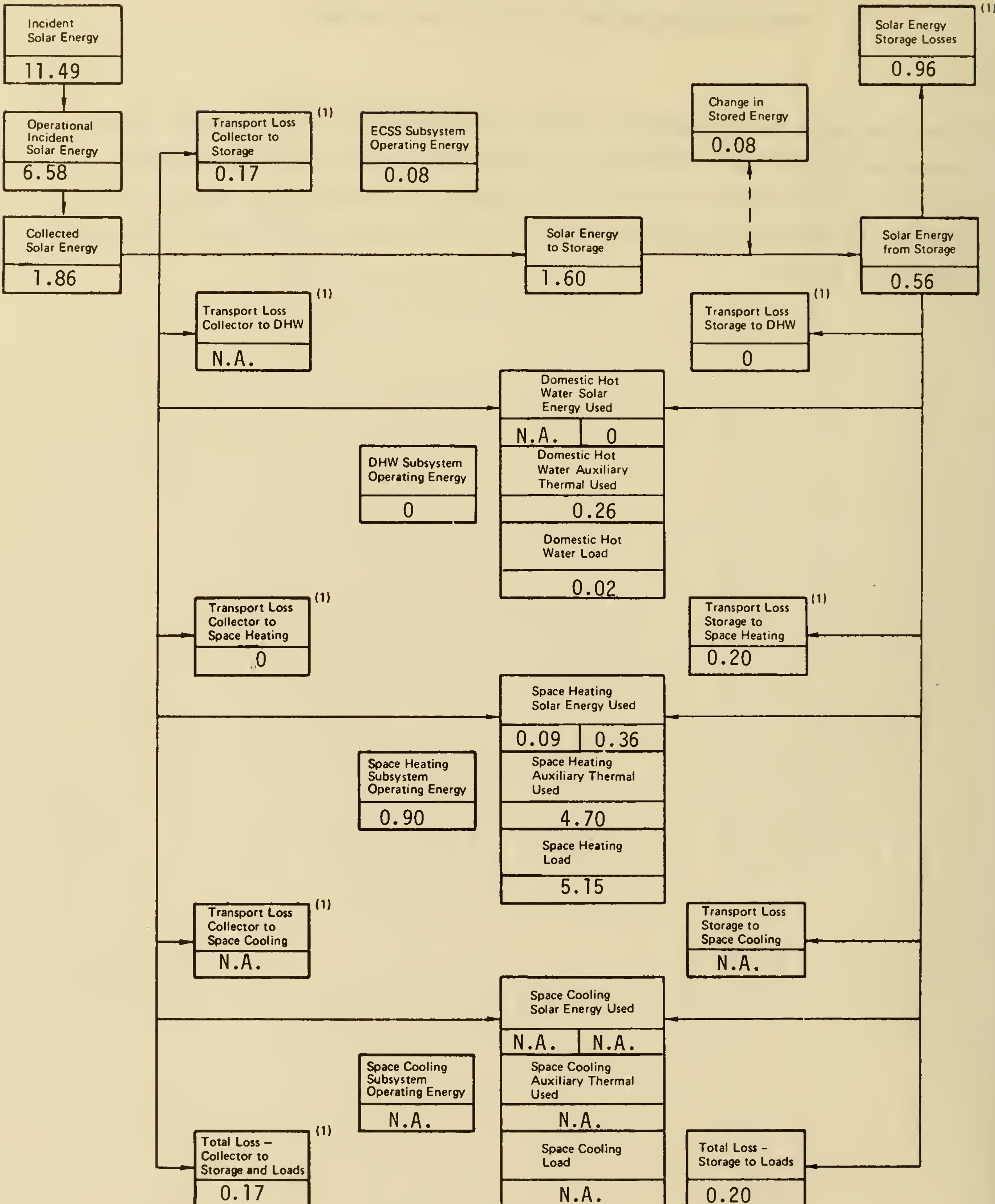
TBAR ==> AVERAGE AMBIENT TEMPERATURE IN DEGREES FAHRENHEIT.

APPENDIX D

MONTHLY SOLAR ENERGY DISTRIBUTION FLOWCHARTS

The flowcharts in this appendix depict the quantity of solar energy corresponding to each major component or characteristic of the Stewart-Teele Mitchell solar energy system for five months of the reporting period. Each monthly flowchart represents a solar energy balance as the total input equals the total output.

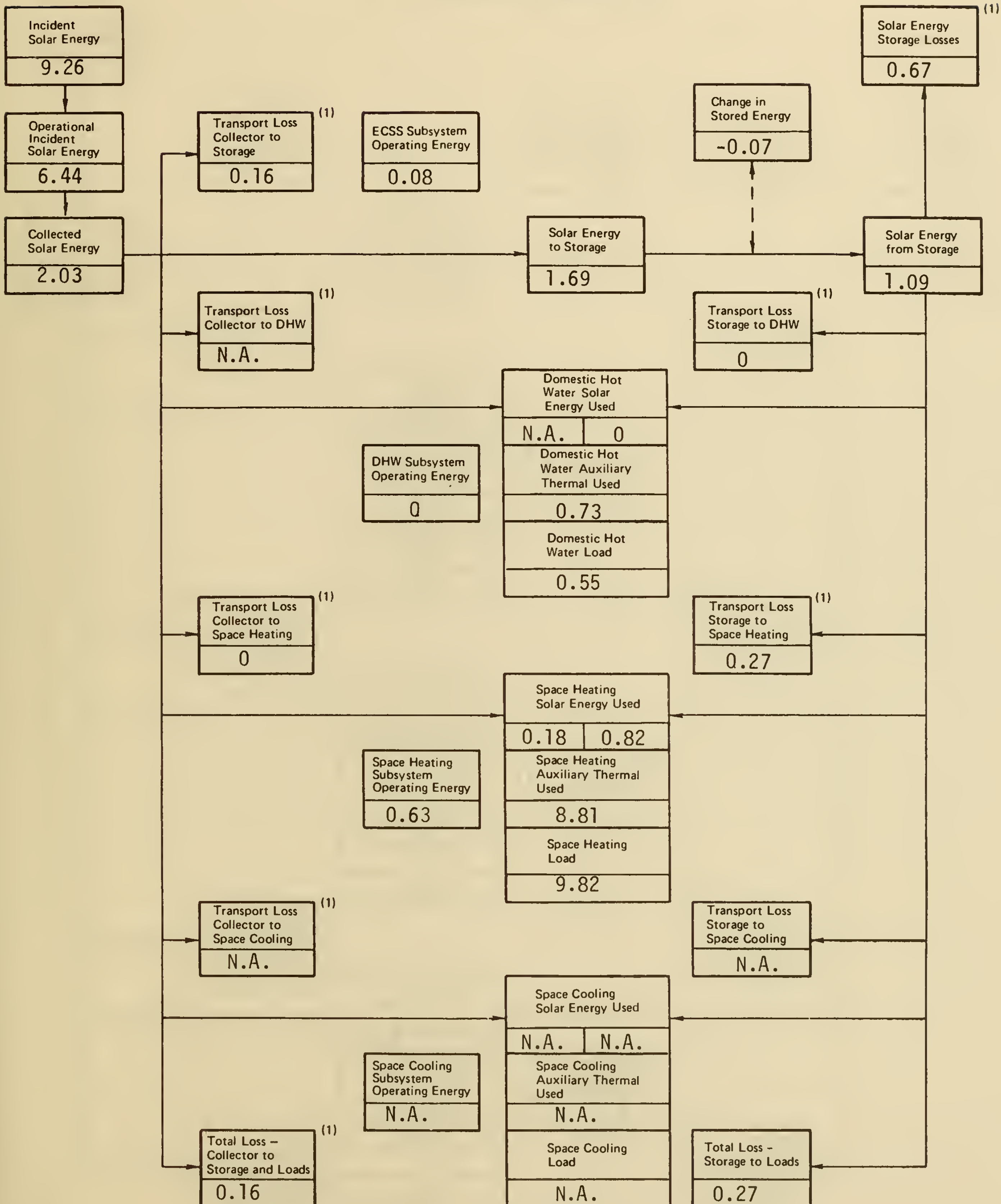
FIGURE D-1. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - NOVEMBER 1978
STEWART-TEELE-MITCHELL



* Denotes Unavailable Data
N.A. denotes not applicable data
(1) May contribute to offset of space heating load (if known – see text for discussion)

S002

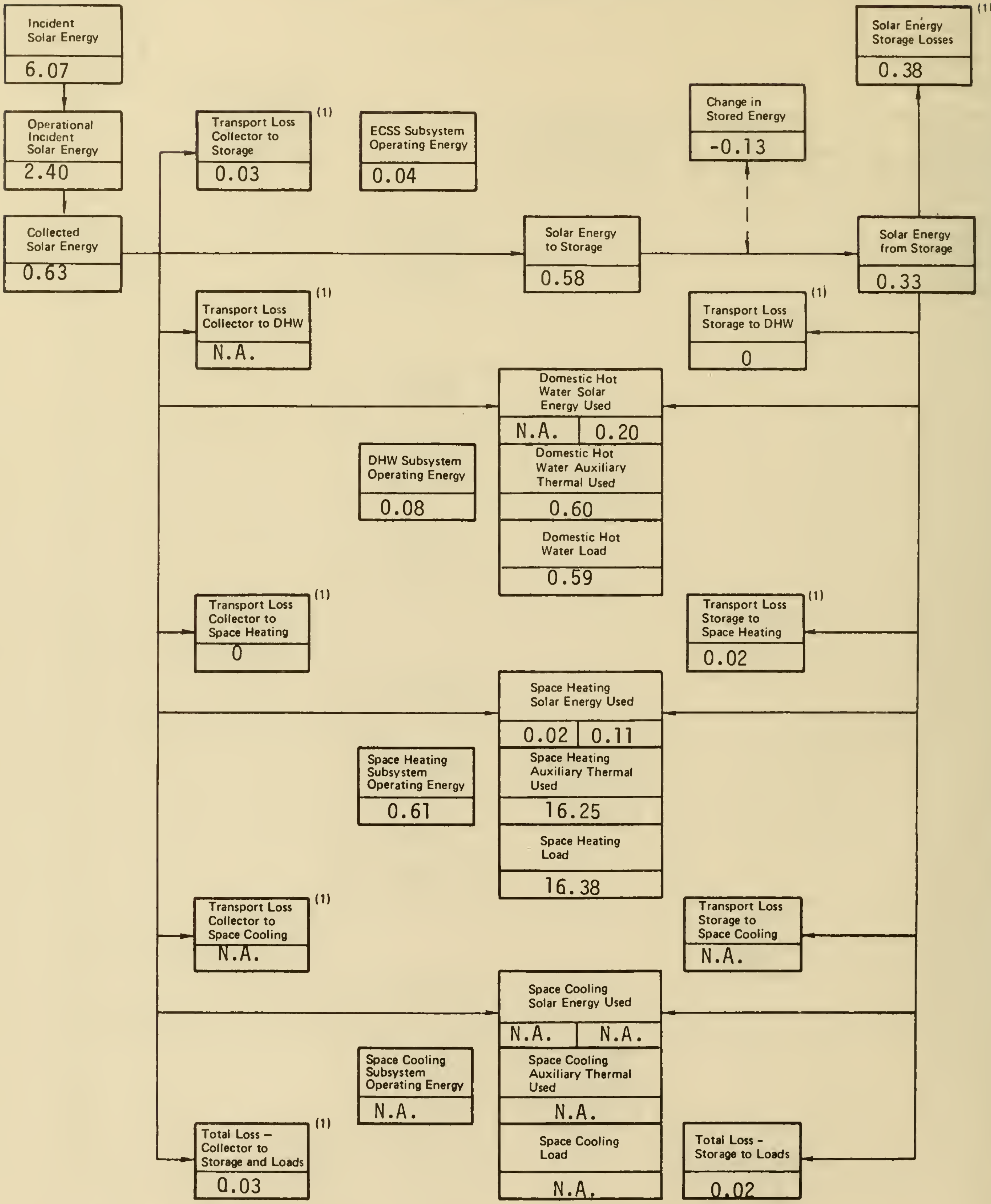
FIGURE D-2. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - DECEMBER 1978
STEWART-TEELE-MITCHELL



* Denotes Unavailable Data
N.A. denotes not applicable data
(1) May contribute to offset of space heating load (if known – see text for discussion)

S002

FIGURE D-3. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - JANUARY 1979
STEWART-TEELE-MITCHELL

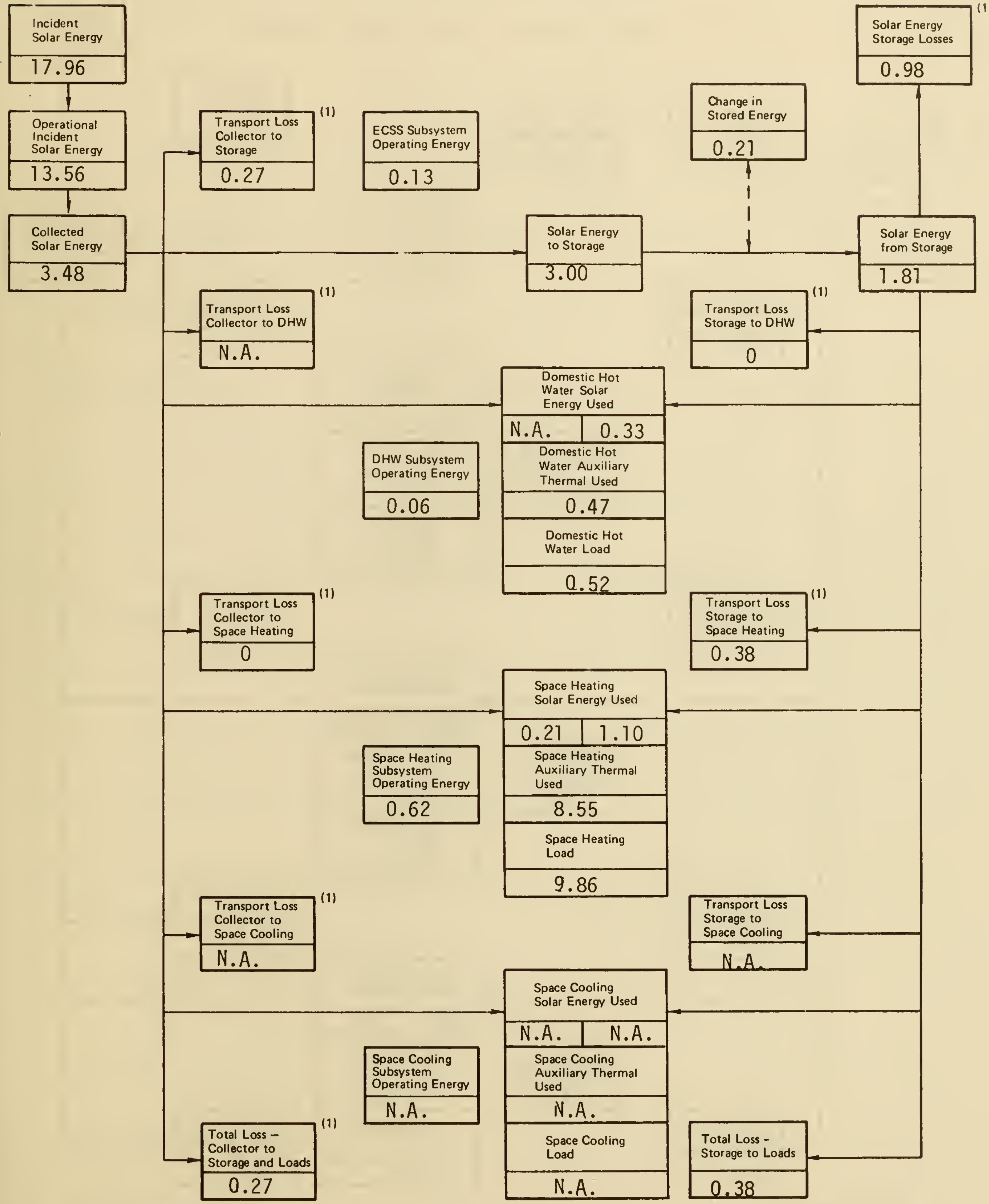


* Denotes Unavailable Data
N.A. denotes not applicable data
(1) May contribute to offset of space heating load (if known – see text for discussion)

S002

FIGURE D-4. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - FEBRUARY 1979

STEWART-TEELE-MITCHELL



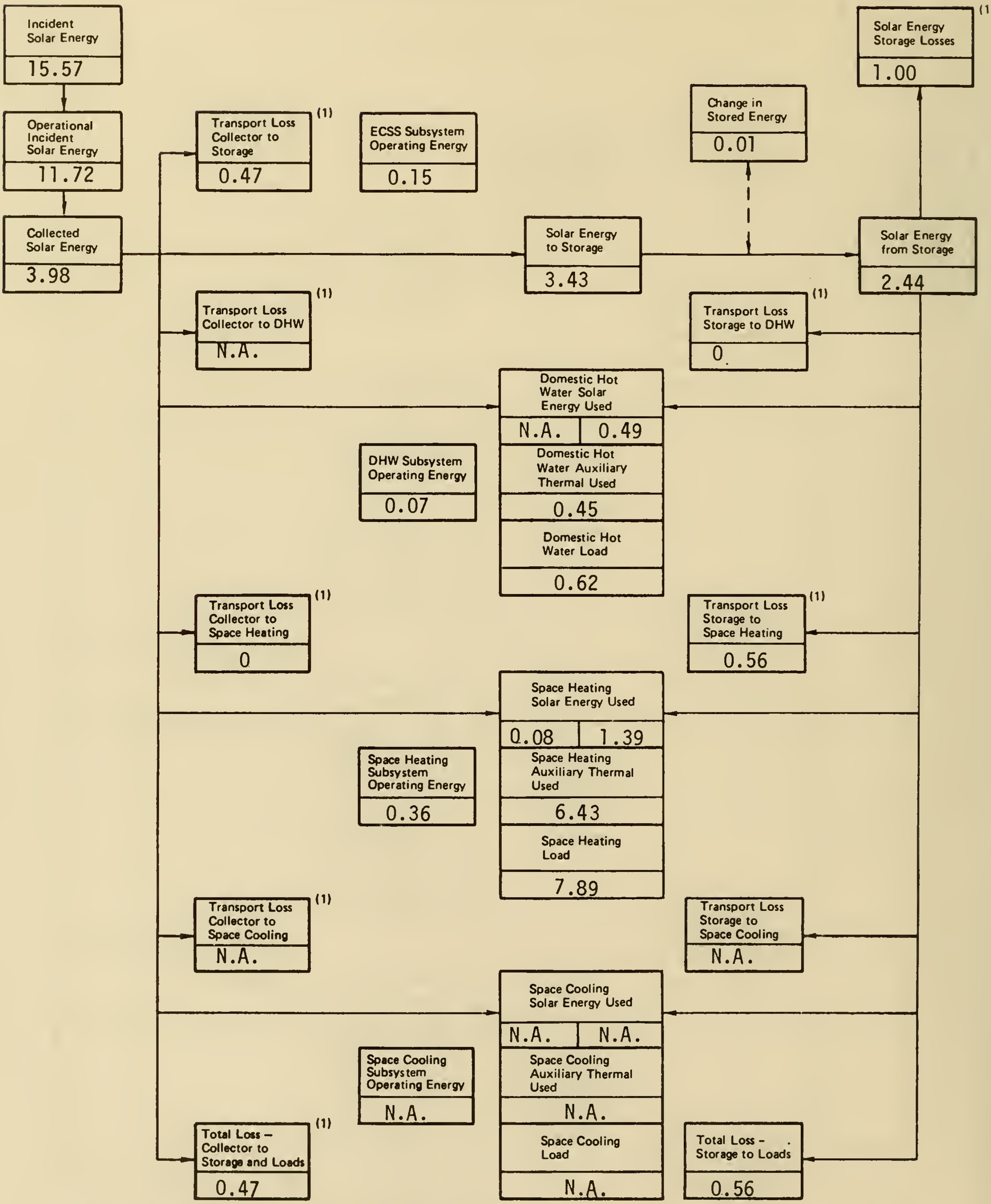
* Denotes Unavailable Data

N.A. denotes not applicable data

(1) May contribute to offset of space heating load (if known – see text for discussion)

S002

FIGURE D-5. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - MARCH 1979
STEWART-TEELE-MITCHELL



* Denotes Unavailable Data
N.A. denotes not applicable data
(1) May contribute to offset of space heating load (if known – see text for discussion)

S002

APPENDIX E

MONTHLY SOLAR ENERGY DISTRIBUTIONS

The data tables provided in this appendix present an indication of solar energy distribution, intentional and unintentional, in the Stewart-Teele Mitchell solar energy system. Tables are provided for five months of the reporting period.

TABLE E-1. SOLAR ENERGY DISTRIBUTION - NOVEMBER 1978
STEWART-TEELE-MITCHELL

- 1.86 million Btu / 100% — TOTAL SOLAR ENERGY COLLECTED
  - 0.45 million Btu / 24 % — SOLAR ENERGY TO LOADS
    - 0 million Btu / 0 % — SOLAR ENERGY TO DHW SUBSYSTEM
    - 0.45 million Btu / 24 % — SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
    - N.A. million Btu / % — SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
  - 1.33 million Btu / 72 % — SOLAR ENERGY LOSSES
    - 0.96 million Btu / 52 % — SOLAR ENERGY LOSS FROM STORAGE
    - 0.37 million Btu / 20 % — SOLAR ENERGY LOSS IN TRANSPORT
      - 0.17 million Btu / 9 % — COLLECTOR TO STORAGE LOSS
      - * million Btu / % — COLLECTOR TO LOAD LOSS
        - N.A. million Btu / % — COLLECTOR TO DHW LOSS
        - * million Btu / % — COLLECTOR TO SPACE HEATING LOSS
        - N.A. million Btu / % — COLLECTOR TO SPACE COOLING LOSS
      - 0.20 million Btu / 11 % — STORAGE TO LOAD LOSS
        - * million Btu / % — STORAGE TO DHW LOSS
        - 0.20 million Btu / 11 % — STORAGE TO SPACE HEATING LOSS
        - N.A. million Btu / % — STORAGE TO SPACE COOLING LOSS
  - 0.08 million Btu / 4 % — SOLAR ENERGY STORAGE CHANGE

* - Denotes unavailable data

TABLE E-2. SOLAR ENERGY DISTRIBUTION - DECEMBER 1978
STEWART-TEELE-MITCHELL

- 2.03 million Btu / 100% — TOTAL SOLAR ENERGY COLLECTED
  - 1.00 million Btu / 49 % — SOLAR ENERGY TO LOADS
    - 0 million Btu / 0 % — SOLAR ENERGY TO DHW SUBSYSTEM
    - 1.00 million Btu / 49 % — SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
    - N.A. million Btu / % — SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
  - 1.10 million Btu / 54% — SOLAR ENERGY LOSSES
    - 0.67 million Btu / 33 % — SOLAR ENERGY LOSS FROM STORAGE
    - 0.43 million Btu / 21 % — SOLAR ENERGY LOSS IN TRANSPORT
      - 0.16 million Btu / 8 % — COLLECTOR TO STORAGE LOSS
      - * million Btu / % — COLLECTOR TO LOAD LOSS
        - N.A. million Btu / % — COLLECTOR TO DHW LOSS
        - * million Btu / % — COLLECTOR TO SPACE HEATING LOSS
        - N.A. million Btu / % — COLLECTOR TO SPACE COOLING LOSS
      - 0.27 million Btu / 13 % — STORAGE TO LOAD LOSS
        - * million Btu / % — STORAGE TO DHW LOSS
        - 0.27 million Btu / 13 % — STORAGE TO SPACE HEATING LOSS
        - N.A. million Btu / % — STORAGE TO SPACE COOLING LOSS
  - -0.07 million Btu / -3% — SOLAR ENERGY STORAGE CHANGE

* - Denotes unavailable data

TABLE E-3. SOLAR ENERGY DISTRIBUTION - JANUARY 1979
STEWART-TEELE-MITCHELL

0.63 million Btu	100%	TOTAL SOLAR ENERGY COLLECTED
0.33 million Btu	53 %	SOLAR ENERGY TO LOADS
0.20 million Btu	32 %	SOLAR ENERGY TO DHW SUBSYSTEM
0.13 million Btu	21 %	SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
N.A. million Btu	%	SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
0.43 million Btu	68 %	SOLAR ENERGY LOSSES
0.38 million Btu	60 %	SOLAR ENERGY LOSS FROM STORAGE
0.05 million Btu	8 %	SOLAR ENERGY LOSS IN TRANSPORT
0.03 million Btu	5 %	COLLECTOR TO STORAGE LOSS
* million Btu	%	COLLECTOR TO LOAD LOSS
N.A. million Btu	%	COLLECTOR TO DHW LOSS
* million Btu	%	COLLECTOR TO SPACE HEATING LOSS
N.A. million Btu	%	COLLECTOR TO SPACE COOLING LOSS
0.02 million Btu	3 %	STORAGE TO LOAD LOSS
* million Btu	%	STORAGE TO DHW LOSS
0.02 million Btu	3 %	STORAGE TO SPACE HEATING LOSS
N.A. million Btu	%	STORAGE TO SPACE COOLING LOSS
-0.13 million Btu	-21 %	SOLAR ENERGY STORAGE CHANGE

* - Denotes unavailable data

N.A. - Denotes not applicable data

TABLE E-4. SOLAR ENERGY DISTRIBUTION - FEBRUARY 1979
STEWART-TEELE-MITCHELL

- 3.48 million Btu / 100% — TOTAL SOLAR ENERGY COLLECTED
  - 1.64 million Btu / 47 % — SOLAR ENERGY TO LOADS
    - 0.33 million Btu / 9 % — SOLAR ENERGY TO DHW SUBSYSTEM
    - 1.31 million Btu / 38 % — SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
    - N.A. million Btu / % — SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
  - 1.63 million Btu / 47 % — SOLAR ENERGY LOSSES
    - 0.98 million Btu / 28 % — SOLAR ENERGY LOSS FROM STORAGE
    - 0.65 million Btu / 19 % — SOLAR ENERGY LOSS IN TRANSPORT
      - 0.27 million Btu / 8 % — COLLECTOR TO STORAGE LOSS
      - * million Btu / % — COLLECTOR TO LOAD LOSS
        - N.A. million Btu / % — COLLECTOR TO DHW LOSS
        - * million Btu / % — COLLECTOR TO SPACE HEATING LOSS
        - N.A. million Btu / % — COLLECTOR TO SPACE COOLING LOSS
      - 0.38 million Btu / 11% — STORAGE TO LOAD LOSS
        - * million Btu / % — STORAGE TO DHW LOSS
        - 0.38 million Btu / 11 % — STORAGE TO SPACE HEATING LOSS
        - N.A. million Btu / % — STORAGE TO SPACE COOLING LOSS
  - 0.21 million Btu / 6 % — SOLAR ENERGY STORAGE CHANGE

* - Denotes unavailable data

TABLE E-5. SOLAR ENERGY DISTRIBUTION - MARCH 1979
STEWART-TEELE-MITCHELL

3.98 million Btu	100%	TOTAL SOLAR ENERGY COLLECTED
1.96 million Btu	49 %	SOLAR ENERGY TO LOADS
0.49 million Btu	12 %	SOLAR ENERGY TO DHW SUBSYSTEM
1.47 million Btu	37 %	SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
N.A. million Btu	%	SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
2.03 million Btu	51 %	SOLAR ENERGY LOSSES
1.00 million Btu	25 %	SOLAR ENERGY LOSS FROM STORAGE
1.03 million Btu	26 %	SOLAR ENERGY LOSS IN TRANSPORT
0.47 million Btu	12 %	COLLECTOR TO STORAGE LOSS
* million Btu	%	COLLECTOR TO LOAD LOSS
N.A. million Btu	%	COLLECTOR TO DHW LOSS
* million Btu	%	COLLECTOR TO SPACE HEATING LOSS
N.A. million Btu	%	COLLECTOR TO SPACE COOLING LOSS
0.56 million Btu	14 %	STORAGE TO LOAD LOSS
* million Btu	%	STORAGE TO DHW LOSS
0.56 million Btu	14 %	STORAGE TO SPACE HEATING LOSS
N.A. million Btu	%	STORAGE TO SPACE COOLING LOSS
-0.01 million Btu	0 %	SOLAR ENERGY STORAGE CHANGE

* - Denotes unavailable data
N.A. - Denotes not applicable data